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Eye-movements and attention. Spatial attention can be allocated to different areas of the visual field within a single eye-fixation, showing that there is some degree of independence between the systems controlling attention and the eyes. Previous investigators have explored the degree of independence by requiring subjects to simultaneously attend to different points in the field and move their eyes to the same or different locations. For example, Klein (1979) reasoned that if the two systems are independent, then subjects should be able to move to their eyes to one location and attend to another without any mutual interference. Although he reports results consistent with this hypothesis, there are methodological problems with his study that make any conclusions suspect.

Baskaran Subramanian in his master's thesis investigated this question with an improved methodology. In his first experiment, subjects were instructed to make a saccade to a particular location in the visual field. Unlike previous research, the saccade signal was

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19. auditory rather than visual, thus precluding the problem of automatic capture of attention by a visual transient. Shortly before the eyes began to move, a visual array was briefly presented and the subject was required to determine which of two letters was present. Subramanian found that letters were more likely to be discriminated in the same location as the target of the saccade showing that subjects were allocating attention to this area as part of the saccade-programming process.

In a second experiment, he investigated whether this relationship between attention and eye-movements was obligatory. Subjects made a saccade to a particular location over a long series of trials. In addition, subjects were provided, prior to each trial, the probable location of a target letter. In the absence of eye-movements, subjects attended to this cued location and gained benefits when the target was presented in that location and suffered costs when it appeared in non-cued locations. When eye-movements were required, however, there were no costs and benefits associated with the cue; instead targets were detected best in the direction of the saccade even when another area was the likely location of the target. Thus, selective attention appears to be a necessary component of saccadic eye-movements and probably is responsible for providing the spatial coordinates to the controlling mechanism.

Visual Selective Attention

Final Report

James E. Hoffman

February 1, 1990

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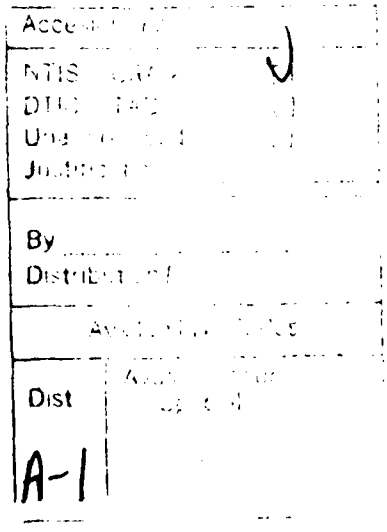

Statement of Problem

Visual information processing appears to operate in two relatively distinct stages (Hoffman, 1978; 1979; Treisman, 1988). The initial stage is a parallel, feature extraction process that produces separate retino-topic maps corresponding to each of several dimensions such as color, orientation, motion, depth, etc. A second stage of focal attention is responsible for integrating the separate features into "object representations". This stage is slow and serial.

Previous research funded by ARO (DAAG29-83-K-0049) explored the possibility that extensive practice in visual detection and search tasks could result in automatic detection of targets that would no longer require the the use of limited-capacity attentional resources. We found that such training did dramatically enhance these skills but that limited-capacity processes continued to set limits in dual-task situations in which the observer was required to monitor several sources of visual information. These inferences were verified by simultaneously monitoring behavioral performance measures as well as components of the event-related brain potential (ERP) that are known to reflect attentional processes. Much of this work is summarized in Hoffman (1986) and Hoffman (in press).

The current work was directed at gaining a further understanding of spatial attention and its role in perceptual skills. An additional project was conducted in the area of language and ERPs.

Summary of Results

Eye-movements and attention. Spatial attention can be allocated to different areas of the visual field within a single eye-fixation, showing that there is some degree of independence between the systems controlling attention and the eyes. Previous investigators have explored the degree of independence by requiring subjects to simultaneously attend to different points in the field field and move their eyes to the same or different locations. For example, Klein (1979) reasoned that if the two systems are independent, then subjects should be able to move to their eyes to one location and attend to another without any mutual interference. Although he reports results consistent with this hypothesis, there are methodological problems with his study that make any conclusions suspect.

Baskaran Subramanian in his master's thesis investigated this question with an improved methodology. In his first experiment, subjects were instructed to make a saccade to a particular location in the visual field. Unlike previous research, the saccade signal was auditory rather than visual, thus precluding the problem of automatic capture of attention by a visual t[illegible]ent. Shortly before the eyes began to move, a visual array was briefly presented a[illegible] the subject was required to determine which of two letters was present. Subramani[illegible]ound that letters were more likely to be discriminated in the same location as the target of the saccade showing that subjects were allocating attention to this area as part of the saccade-programming process.

In a second experiment, he investigated whether this relationship between attention and eye-movements was obligatory. Subjects made a saccade to a particular location over a long series of trials. In addition, subjects were provided, prior to each trial, the probable location of a target letter. In the absence of eye-movements, subjects attended to this cued location and gained benefits when the target was presented in that location and suffered costs when it appeared in non-cued locations. When eye-movements were required, however, there were no costs and benefits associated with the cue; instead targets were detected best in the direction of the saccade even when another area was the likely location of the target. Thus, selective attention appears to be a necessary component of saccadic eye-movements and probably is responsible for providing the spatial coordinates to the controlling mechanism.

Attention and Objects. Is attention allocated to spatial positions or to "objects"? Our phenomenlogical experience suggests that it is objects and research by John Duncan (1984) supports that claim. Duncan examined people's ability to divide attention between separate features that either belonged to the same or different objects. Divided attention performance was superior in the same object condition. Unfortunately features also tended to be closer together in this condition so the results are also consistent with the claim that attention is allocated as a "spotlight" to spatial areas.

Sharon Zerlin in her master's thesis designed an experiment to disentangle spatial proximity and objectness. In addition, she sought to use a more convincing method of defining what constitutes an object. She had subjects identify a letter that was on a moving surface. "Noise" letters could appear on the same surface (same object condition) or a different surface moving in the opposite direction (different object condition). In addition, the noise letters could appear either close to or far from the target letter. The degree of interference caused by the noise was used as the measure of attentional allocation. The results were clear. Both spatial proximity and objectness were independent determinants of attention. Features on the same object and close to the target are processed more than features further away and /or on a different object.

Temporal Integration and saccades. In pilot work for her doctoral dissertation, Sharon Zerlin has been studying the process by which we integrate information across fixations. It seems likely that there is a visual memory that allows information from the previous fixation to be integrated with information from the current fixation. Is this memory limited in capacity and what are its decay characteristics? Zerlin modified the partial report procedure of Sperling (1960) to investigate this. Subjects see a rectangular array of letters in one fixation. Following an eye movement to a new fixation point, they receive a visual cue indicating one letter for report. We have found that subjects can reliably report the cued letter at short delays of the cue but that performance deteriorates rapidly with increases in cue delay. Comparable performance is obtained in a fixation condition when no changes in eye position are allowed. This preliminary result suggests that there is a rapidly decaying memory representation that allows for the integration of information across saccades. In addition, it appears that this memory is defined in spatio-topic coordinates rather than retinal coordinates (subjects subjectively see the bar over the position of the letter that appeared in the bar's screen position, rather than its retinal position). Further experiments will be required to examine the question of capacity limits.

N400 and Semantic Congruity. Arti Nigam's master's thesis investigated the relation between the N400 component of the ERP and semantic anomaly. Previous research by Kutas and Hillyard (1982) found that a large negative component with a latency of about 400 msec occurred in the ERP when subjects encountered a semantically anomalous word. For example, the sentence frame: "He likes cream and sugar in his _____" followed by the word "socks" would elicit an N400. This N400 could be tied to any of several different levels in language representation. It could index the surface level of the word itself or it could be associated with the "deep" or semantic level of meaning.

Nigam evaluated these possibilities by comparing the usual N400 situation with one in which the last word is replaced by a picture representing the same concept (eg. a line drawing of socks). Pictures and words have very different surface representations but can share the same underlying concept. Thus, if the picture condition produces an N400 with the same latency, amplitude, and scalp distribution as the word condition, one could conclude that the N400 is indexing processing at a semantic level. This is exactly what she found. It should be noted that subjects could not not have simply been naming the pictures and responding on the basis of the name because picture naming is

about 200 msec slower than word naming and this would have produced a difference in latency between the two conditions. No such latency shift was observed.

Summary

We found that visual attention is not only important in search and detection tasks but plays a role in the control of action systems such as eye-movements. Subjects must attend to the spatial position that is the target of the eye-movement. We believe that that this process is important for two reasons. One is that saccades are not randomly distributed in a scene but tend to be concentrated on areas of high interest or information density. They are guided by the information acquired through spatial attention. Second, attending to the target area of a saccade may produce a visual memory representation of that area which can be compared with the information available at the fovea after the eye-movement has been executed. These should match and a failure to do so would constitute evidence that the scene had moved in addition to the eye. Thus, this mechanism could provide part of the information required for perceptual stability in the face of eye-movements.

Attention can be guided not only by the spatial coordinates available to the visual system but also by the structure of the surfaces and objects that are visible. We found that both of these are important in the allocation of attention. It still remains to be determined what constitutes an object to the attentional system. We have started with perhaps the most primitive and basic cues as to object structure: namely, that features sharing a common, rigid motion should be grouped as an object but clearly there are a variety of other kinds of visual information which would be important as well.

Finally, we have also used the ERP to investigate the kind of representations that occur during language processing. We found that the N400 reflects a level of semantic processing that is common for both pictures and words. Thus our results are consistent with the claim that there is an underlying semantic representation that is neither perceptual nor linguistic.

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